the screen are necessarily much less bright than the clouds themselves, and when these latter are pale or nearly uniform, or again when the daylight is feeble, the images in the dark room have not the clearness necessary for making good observations.

The preceding considerations have led me to construct a new nephoscope, which will render observations in the neighborhood of the zenith easy, and obviate the inconveniences of the dark room. It consists essentially of a horizontal frame upon which are stretched two orthogonal systems of parallel and equi-distant threads, forming a lattice. By standing above this frame and looking at the clouds through it, their direction may be determined by turning the frame in such a manner that one of the systems of threads will be parallel with it; the other system of threads is then perpendicular to the motion of the clouds and enables us to determine their relative velocity. As a matter of fact the observation is not made directly, but with the aid of an inclined plane mirror placed below the frame. This arrangement has a twofold advantage; first it relieves the observer from an uncomfortable position; and in the second place, for the same elevation of frame, it increases the useful length of the instrument by the distance which separates the eye from the mirror. The position of the eye is fixed by means of an eye hole which may be furnished with a piece of smoked glass, if it is thought necessary.

In the model constructed according to our instructions by Richard, the frame is circular and has a diameter of 0.65 meter; it is supported by three rods resting upon an annular metallic plate. This is the movable part of the instrument. The fixed base is formed of a wooden disk, the upper side of which is divided into degrees; this disk is set and fixed immovably upon a pillar or some kind of a pedestal. The support of the mirror, fixed to this wooden disk, fits the central part of the annular metallic plate and serves it as an axis of rotation. Upon the edge of this bevelled plate are engraved four reference lines, traced parallel to the threads of the frame. The direction is read upon the graduated scale of the disk, opposite to the reference mark on the side from whence the clouds come. The height of the instrument above its socket is 1.10 meters, but on account of the reflection from the mirror it seems as though the eye was exactly 1.50 meters below the frame. The space from one thread to the other, upon this frame, is 0.075 meter or 1/20 the distance from the eye. Consequently, the relation of the height of the clouds, H, to their velocity V is given, as in the dark nephoscopic room, by the formula:

$$\frac{H}{V} = 20\,\frac{t}{n},$$

n being the number of spaces passed over by the observed point and t the time occupied in passing over. Two nephoscopes of this pattern have been in use for more than six months at stations of the municipal meteorological service, where they are used specially in the study of the influence of Paris upon the movement of the upper currents. For researches of this kind, it was indispensable that the observations at each station should be made in close proximity to the zenith; and it was, therefore, advisable to put into the hands of the observers an instrument the field of which was limited to this part of the sky. In ordinary meteorological observations it will be advantageous to make use of this nephoscope whenever the layer of clouds whose motion it is intended to determine is situated in the neighborhood of the zenith.

THE EARTHQUAKE OF JANUARY 20, 1904, AT WASHINGTON, D. C.
By Prof. C. F. Marvin.

The fourth great earthquake of very distant origin to be recorded at the Weather Bureau occurred on January 20, 1904,

at $9^h 58^m 38^s$ a. m., seventy-fifth meridian time. While the disturbance at Washington was wholly imperceptible to ordinary sensations, yet the horizontal movement of the ground was greater than in any of the earthquakes thus far recorded.

The apparatus by which this earthquake was recorded has already been described in the MONTHLY WEATHER REVIEW for June, 1903, page 271.

It is interesting to note, in connection with this earthquake, that for fully twenty-four hours preceding the disturbance the seismograph record showed minute waves of earth movement extending more or less continuously throughout the whole time. It is also to be remarked in this connection that a vast area of high barometer dominated the whole eastern area of the United States from January 18 to 20.

It is not to be inferred that the writer argues that there is any necessary connection between the earthquake and the high barometer. This is hardly probable, although the high barometer may in some way have contributed to produce the minute pulsations referred to.

The waves of displacement, as shown by the record, are unusually regular and of a simple sinusoidal type. The period is also, on the whole, relatively long.

The following table gives the times of the pricipal features of the disturbance. The north and south component of horizontal motion only is recorded:

January 20, 1904, a. m., seventy-fifth meridian time.

	h.	m.	s.	h.	m.	s.
First preliminary tremors	9	58	38 a. m.			
Second preliminary tremors	10	3	52 a. m.			
Principal portion began	10	8	50 a. m.			
Principal portion ended	10	11	50 a. m.			
Maximum waves at	10	11	16 a. m.			
End of earthquake	10	51	51 a. m.			
Duration of first preliminary tremor				0	5	14
Duration of second preliminary tremor				0	4	58
Average period of waves in principal portion (seven complete waves in $2^m 45^s$)						23.6
Period of slow waves of principal portion						25.8
Period of shorter and maximum waves of principal portion						19.0
Period of uniform waves in final portion						17.3
Period of pendulum						26.0
Maximum double amplitude of actual displacement of earth at seismograph						0.4 mm.
Magnification of record						10

LUNAR HALO OF JANUARY 30, 1904.
By Rev. F. L. Odenbach, S. J.

A halo was observed on January 30, 1904, at Ignatius College Observatory, Cleveland, Ohio, 7:20 p. m., seventy-fifth meridian time.

The sky at the time was evenly covered with a thin pallium of stratus; stars of the first magnitude were visible through it.

I observed four of the so-called Newton's rings around the moon.

I Ring.—Blue, white, yellow, red, 2°.
II Ring.—Blue, green, yellow, red, 6°.
III Ring.—Blue, green, red, 10°.
IV Ring.—Red, 12° to 15°.

It was very brilliant, in fact the most perfect and elaborate I have ever seen. The measurements were taken with a theodolite, the tube of which is plain and without lenses, made for this kind of work. The angles were read in a hurry and to the nearest degree, since I followed the same method as in the observations of the Hevelian halo of 90° in 1901, and with the same luck, as the phenomenon lasted only for about five to eight minutes.

After that the pallium thickened and finally broke into denser cloud, strato-cumulus, the altitude of which I measured and found to be 4783 feet (method described in 8th Annual Report of the Ignatius College Observatory, 1902–03).

The most prominent part of the corona was the yellow and

red of the first series of colors. The red of the fourth ring was faint and seemed to be fringed with white.

The time of observation was so short that I can give nothing more in the way of facts. But from the general impression received I think that if time had allowed I could have made out not only the primary colors but also the mixture as given by Newton for his 1, 2, 3, 4 orders. The three first of these he actually observed in June, 1692, and calculated the rest.

STUDIES ON THE CIRCULATION OF THE ATMOSPHERES OF THE SUN AND OF THE EARTH.

By Prof. FRANK H. BIGELOW.

III.—THE PROBLEM OF THE GENERAL CIRCULATION OF THE ATMOSPHERE OF THE EARTH.

THE CANAL THEORY.

In my Cloud Report, Annual Report of the Chief of the Weather Bureau, 1898–1899, Volume II, chapter 11, it was shown that for the United States the canal theory of the general circulation of the atmosphere, as worked out by Ferrel and by Oberbeck, does not sufficiently conform to the observations on cloud motions to be a satisfactory solution of the problem. The Report of the International Committee, 1903, by H. H. Hildebrandsson, reached the same conclusions for nearly all parts of the Northern Hemisphere, and, therefore, that canal theory may be finally abandoned. The following paper contains some suggestions on this subject which seem promising, and adapted to laying the foundation for a new development of this branch of theoretical meteorology. The physical facts to be accounted for may be found in the two publications referred to, also in my Papers on the Statics and Kinematics of the Atmosphere in the United States,[22] and they need not be recapitulated in this place.

THE GENERAL EQUATIONS OF MOTION.

Referring to the well-known general equations of motion as summarized in the Weather Bureau Cloud Report, from equation (155) we have

(1)
$$-\frac{1}{\rho}\frac{\partial P}{\partial x} - \frac{\partial V}{\partial x} = \frac{du_1}{dt}.$$
$$-\frac{1}{\rho}\frac{\partial P}{\partial y} - \frac{\partial V}{\partial y} = \frac{dv_1}{dt}.$$
$$-\frac{1}{\rho}\frac{\partial P}{\partial z} - \frac{\partial V}{\partial z} = \frac{dw_1}{dt}.$$

These are transformed into the first form of polar equations (181), these again into the forms (200) and (201) in succession, so that the common integral becomes

(2)
$$\int -\frac{dP}{\rho} = \int \left(\frac{du}{dt}\partial x + \frac{dv}{dt}\partial y + \frac{dw}{dt}\partial z \right) + V - C.$$

The usual method of development proceeds by taking

(3)
$$u = \frac{\partial x}{\partial t}, \quad v = \frac{\partial y}{\partial t}, \quad w = \frac{\partial z}{\partial t}, \quad \text{so that}$$

(4)
$$\int -\frac{dP}{\rho} = \int (udu + vdv + wdw) + V - C$$
$$= \tfrac{1}{2}(u^2 + v^2 + w^2) + V - C$$
$$= \tfrac{1}{2}q^2 + V - C.$$

This is the ordinary form of the equation of motion on the rotating earth as given in treatises on hydrodynamics, as in Lamb, p. 22, and Basset, Vol. I, p. 34, and is known as Bernoulli's Theorem. C is not an absolute constant, but is the function of the parameter of a stream line; and in the atmosphere, where the flow takes place in stratified layers having different temperatures and angular momenta, it changes from one stratum to another.

It is also possible to integrate these terms along an arbi-

[22] Monthly Weather Review, Vol. XXX, pp. 13, 80, 117, 163, 250, 304, 347.

trary line, $s = \int ds = \int (dx, dy, dz)$, and in this case the derivative relative to the velocity will give acceleration along ds; that is, we have $\dot{q}ds$ instead of qdq, and under some circumstances this may prove to be an advantageous method. In meteorology this will depend, however, upon whether the one or the other set of terms that are required are most practically observed, as line integrals may be readily computed for either of these systems.

LINE INTEGRALS IN THE ATMOSPHERE.

The principles of the canal theory of circulation have been applied by V. Bjerknes[23] and J. W. Sandström[24] in their papers on circulation, under the form of line integrals around arbitrary closed curves in the atmosphere. Thus, the circulation is expressed by them, with the vertical and horizontal components of the total enclosed curve, as

	Total circulation.		Relative component.		Earth's component.

(5) $\quad C_a \quad = \quad C \quad + \quad C_c$

(6) $\quad \int q_a ds \quad = \int q \, ds \quad + 2\,\omega_0 S_1$

(7) $\quad \int \frac{dq_a}{dt}ds \quad = \int \frac{dq}{dt}ds + 2\,\omega_0 \frac{dS_1}{dt}$

(8) $\quad -\int \frac{dP}{\rho.ds}\cdot ds = \int \dot{q}\,ds \quad + \frac{d}{dt}\cdot 2\,\omega_0 \int \tfrac{1}{2}\,\varpi \cos i \cos \theta\,ds + R$

(9) $\quad -\int \frac{dP}{\rho} \quad = \int \dot{q}\,ds \quad + 2\,\omega_0 \cos\theta\cdot\frac{dS}{dt} + R$

Equation (7) is the time rate of change.

C_a = the line integral of the tangential component of total velocity.

C = the line integral of the relative velocity (tangential.)

C_c = the line integral of the velocity of a point on the moving earth itself (tangential).

(q_a, q, q_c) = the velocities; $(\dot{q}_a, \dot{q}, \dot{q}_c)$ = the accelerations.

R = friction; ω_0 = the angular velocity of the earth.

P = pressure; ρ = density.

i = the angle on the plane of the parallel of latitude that ds makes with the direction of a moving point of the earth.

S_1 = the projection of the closed curve S on the plane of the equator for the polar distance θ.

These integrations involve an accurate knowledge of the pressure, density, and acceleration at numerous points along the chosen closed curve, and this it is very difficult to obtain by practicable observations. The variation of S can be found more readily. Several illustrations are given by the authors in applying the theory to the general circulation of the atmosphere and to the local cyclones and anticyclones, but these illustrations do not seem to conform satisfactorily to the conditions observed in North America, as will be set forth in the other papers of this series and in a full report on the subject.

There arises no question with respect to any of the terms of the equation except the one containing $\frac{dS_1}{dt}$, which appears to be an addition to the usual form of the equation of motion on the rotating earth. As has been shown by V. Bjerknes, if the angle θ can be taken constant for a given relatively small closed curve, we have

(10)
$$2\,\omega_0\,\frac{dS_1}{dt} = 2\,\omega_0 \cos\theta\,\frac{d}{dt}\int \tfrac{1}{2}\,\varpi \cos i \, ds,$$

where i is the angle that the element ds makes with the parallel of latitude, or the angle between the two radii of an ele-

[23] Meteorol. Zeitschrift, March, 1900; April, 1900; November, 1900; March, 1902.
[24] Kon. Svens. Vet. — Ak. Handlingar, Bd. 83, No. 4; Meteorol. Zeitschrift, April, 1902; Vetens. Ak. 1902, No. 3.